Analysis of US Civil Rotorcraft Accidents from 1990 to 1996 and Implications for a Safety Program

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A NASA Ames Research Center analysis of rotorcraft accident data identified safety issues that could lead to a reduction in accidents. The primary source of data was summaries of National Transportation Safety Board (NTSB) accident reports. Lower cost helicopters have more accidents than do higher cost helicopters, despite flying fewer total hours, but they have less-serious accidents. The most dramatic division in rotorcraft accidents is between private pilots and professional pilots. Private pilots have more accidents per flight hour than professionals. Pilot error plays a prominent role across the board as either a main cause or contributing factor. Judgement error, in particular, is more likely to lead to a fatal accident than are other types of causes. Accidents with private pilots and those with professional pilots require different solutions. NASA's near term approach to improving rotorcraft safety addresses improving the capability of the private pilot. NASA is doing this by providing training aids to flight schools and using the internet to distribute safety information via a safety website. The site NASA has created contains helpful information that was previously difficult to find in one location. NASA will develop computerized training modules to be used in conjunction with ground and flight instruction. These two projects, the website and training modules, are aimed at raising safety awareness and increasing pilots' comprehension of helicopter operations.

INTRODUCTION

The database of accidents used in this analysis was developed from summary data received from the National Transportation Safety Board (NTSB). The analysis, started in 1997, was limited to recent accidents (1990 - 1996) to ensure that the issues raised are ongoing concerns. During this period, the NTSB initiated a total of 1396 accident investigations. The investigation of 1165 accidents was sufficiently complete by January 1997 to include a probable cause and a complete description of the events. This subset which formed the basis for the present analysis, represents an average of 200 rotorcraft accidents and 70 fatalities per year. These accidents resulted in a total of 491 deaths.

ACCIDENT ANALYSIS

Rotorcraft Accident Rate Comparison

Commercial air carriers are generally considered to be the safest form of air travel. So the airline accident statistics provide a benchmark against which to compare helicopter accidents. Figure 1 shows a comparison of airline and helicopter accident statistics. Accident rates and fatal accident rates are shown for each mode of transport. The airline fatal and total accidents rates are about one tenth those of the corresponding helicopter rates.

The fact that fatal accidents make up approximately the same proportion of the total rate for helicopters as for airliners suggests that helicopter accidents and airliner accidents are about equally survivable. That is, the likelihood of a fatal accident, given an accident has happened, is about the same for both modes of travel. Helicopters are more likely, however, to have an accident – by a factor of ten.

This raises the question, why are helicopters more likely than airliners to have accidents? There are four general areas of difference between helicopters and airliners. These are pilot, equipment, environment, and mission. Airline pilots are highly trained and, generally, highly experienced. Helicopter pilots run the full gamut from students through weekend pilots to highly trained professionals. Similarly airline equipment is high-end, state of the art. While some of the most expensive helicopters have turbine engines and sophisticated avionics, most are piston powered, VFR-only certified aircraft. The helicopter operating environment differs greatly from that of the airliner. Airliners are controlled by Air Traffic Control (ATC) from push back to shut down. Helicopters operate mostly in uncontrolled airspace. Finally the missions differ considerably. While airliners fly point-to-point at altitude, helicopters have a wide variety of distinctive missions, many with specific hazards.

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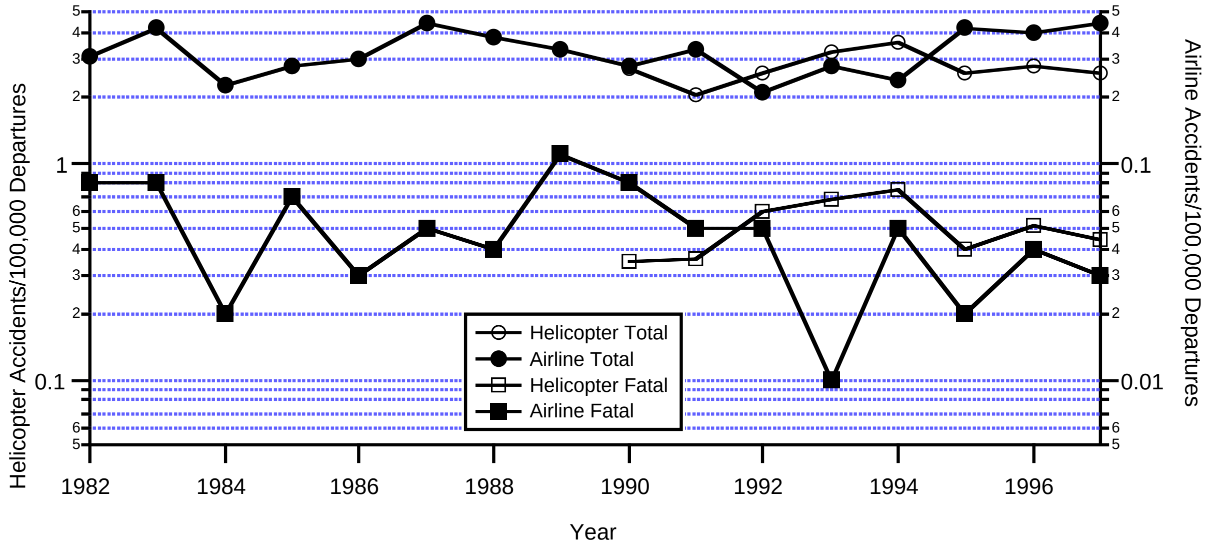

Fig. 1. Total and Fatal Accident Rates for Helicopters and Airlines (per 100,000 departures) (FAA Statistical Handbook of Aviation)

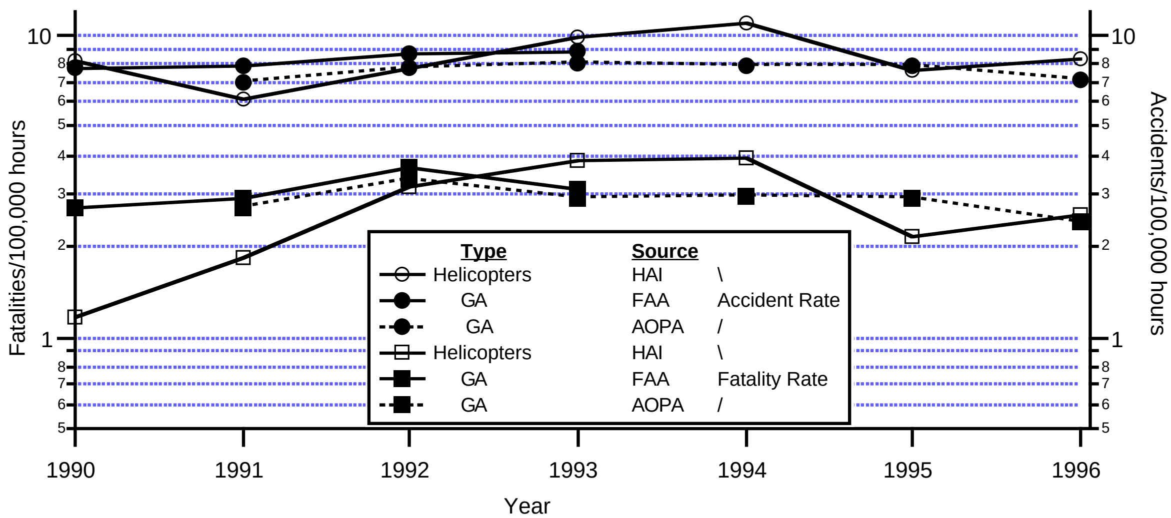

Fig. 2. Accident and Fatality Rates for Helicopters and General Aviation (per 100,000 hours)
Note: Statistics for GA are shown from FAA and AOPA to cover the time range. [123]

Compared with airliners, general aviation is much like helicopters, regarding pilot population, equipment and environment. General aviation lacks, however, many of the mission risk factors of helicopters, such as hover and external loads. Figure 2 shows a comparison of helicopter and general aviation accidents and fatalities. Total and fatal rates are comparable for helicopters and general aviation. These results suggest that the distinctive characteristics of helicopter missions do not play a major causative role in the higher rate of accidents compared to airliners. Rather factors common to helicopters and general aviation may drive the accident rate.

Analysis By Cost

With mission factors ruled out, there are now three factors that might determine the helicopter accident rate: pilot, equipment and air traffic control environment. To break these out, different categories of helicopters were examined. Moving from lower to higher cost helicopters, the equipment becomes more sophisticated and the pilots more highly-trained and experienced. Control environment, on the other hand, is relatively constant, regardless of aircraft cost.

Helicopters were grouped into four cost categories for a broader analysis. These categories were based on the cost of a newly equipped aircraft (at 1994 prices). In order to determine whether the accident rate varied across the fleet, a comparison was made between the accident rates of the low and very high cost groups.

Table 1. 1990-1996 Accident Rates by Aircraft Cost

	Total	Low $0 – 0.6M		Medium $0.6 – 1.5M		High $1.5 – 4M		Very High >$4M	
	#	#	%	#	%	#	%	#	%
Fleet size (1994)	11459	7005	61.1%	2727	23.8%	1015	8.9%	473	4.1%
Accidents	1165	756	64.9%	305	26.2%	76	6.5%	28	2.4%
% of fleet of cost category*			10.8%		11.2%		7.5%		5.9%
People involved	2398	1253	52.3%	874	36.4%	137	5.7%	134	5.6%
Average # people/accident	2.06	1.66		2.87		1.80		4.79	

Note: Percentages are based on total within each row except for *

The estimated rates are high because the flight hour data, used for the denominator, were incomplete. Flight hour data were only available for three very high-cost and eleven low-cost models.[4] Using these numbers as estimates of total usage in each category, the accident rate for the low cost category was more than five times higher than the very high cost category. This difference is probably an underestimate, since the flight hour data for the very high cost aircraft was much less complete than that for the low cost category. The accident rate for very high cost helicopters is comparable to that for airliners.

The difference in accident rate between low cost and very high cost aircraft is not attributable to control environment since both groups fly mostly uncontrolled by ATC and mostly VFR. Rather the difference can be attributed to differences in pilots and equipment. The analysis that follows examines these differences, and looks at mission factors that influence subsets of accident statistics.

Of the 1165 accidents examined, most involved lower cost helicopters. Almost two thirds fell into the Low Cost category, one quarter into Medium, 7% into High, and 2% into Very High (see Table 1). Over the seven year period about 11% of the Low and Medium cost fleets were involved in accidents, while 8% of the High cost fleet and only 6% of the Very High cost fleet were involved in accidents. Thus the odds of a lower priced rotorcraft having an accident are greater than are the odds for a higher priced vehicle.

Damage

The aircraft damage data reveals a difference between the cost categories (see Figure 3. Definitions of damage categories are presented in Appendix A). Substantial damage can result from relatively benign accidents such as hard landing and practice autorotations.

Since the high end helicopter pilots seem to avoid these types of accidents, there is no peak in the substantial damage category like there is for the low end helicopters. If one assumes that all helicopter pilots encounter similar hazards, then it follows that pilots of more expensive aircraft can handle minor situations in ways that avoid damage. Injury analysis shows a similar trend.[5]

Analysis by Cause

The NTSB reports contained detail cause information which were consolidated into fewer, more manageable cause categories. In the data examined, aircraft problems are by far the most common cause of helicopter accidents. For helicopters, the next most common causes are pilot experience, in-flight decision, environment, and inadequate pre-flight, respectively (see Figure 4). The 'aircraft problems' category is very broad, encompassing design, manufacturing, and maintenance problems, as well as inadequate inspection. This category by itself merits further analysis. This analysis reiterates the pilot versus equipment dichotomy. Aircraft problems comprise about half of the high end helicopter accidents, while pilot skill problems account for 70% of the low-end accidents.

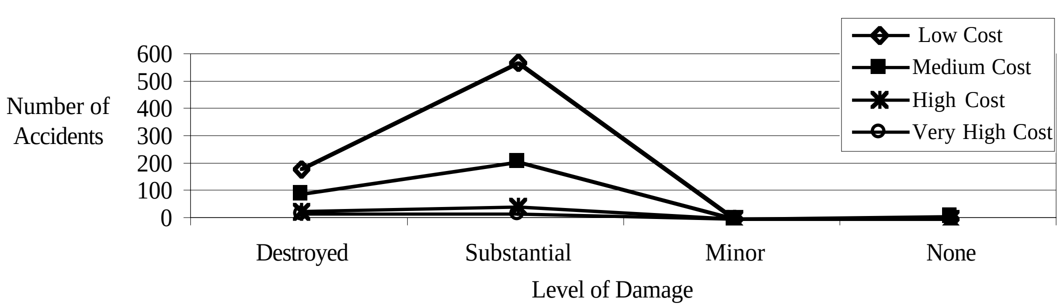

Fig. 3 Damage by Aircraft Cost Category

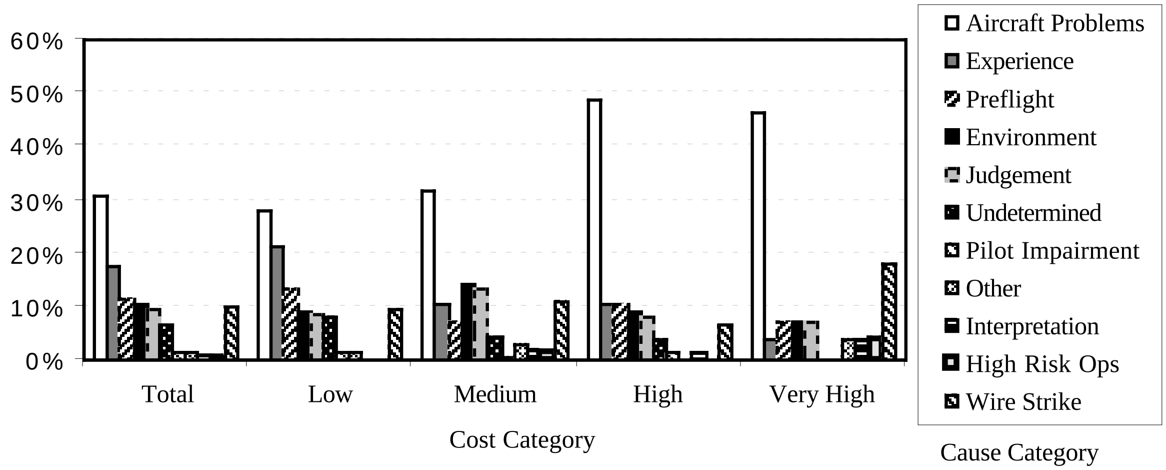

Fig. 4 Accident Causes by Aircraft Cost Category

Analysis By Mission

Mission factors do not make the overall accident rate higher than that of other segments of aviation, but they do affect the accident rates associated with each mission. The following mission analysis highlights more clearly the role of pilot skill level. See definitions for type of operation, or mission, in Appendix B.

Fleet Activity

The FAA conducted a rotorcraft activity survey in 1989.[4] This survey was limited by a low response rate and gives only a rough estimate. It revealed the following information. The registered fleet in 1989 consisted of 10,400 rotorcraft. Of these, 72% or 7488 were active (meaning the aircraft flew one hour or more during the year). On average, each aircraft flew about 390 hours for a total of 280 million hours for the fleet. Aircraft used primarily for air taxi and business comprised 34% of the fleet, aerial observation 17%, and personal use about 14% (Figure 5). The personal use rotorcraft had a very low number of flight hours per helicopter and the lowest number of total fleet hours of all missions. On the other hand, air taxi and aerial observation flew the greatest percentage of total flight hours and made up the largest percentages of the fleet. These figures differ significantly from the accident profiles, where personal, instruction and aerial application operation accounted for the highest percentage of accidents, described below.

Accidents

The type of operation having the highest frequency of accidents varies across the cost categories (see Table 2 – largest categories are highlighted). For the least expensive group, the majority of accidents occur during personal, instruction or aerial application flights. The accidents in the next cost group are concentrated in non-scheduled air taxi. High and Very High cost rotorcraft accidents occurred primarily during positioning, external load and miscellaneous missions. These differences reflect differences in how the various cost categories of aircraft are used.

Table 3 shows the statistics for accidents grouped by mission. Note that the public use category overlaps with other categories, since it is defined by regulation not by mission. Personal and instruction flights result in the most accidents, together accounting for 35% of the database. The accident rate per 100,000 flight hours for personal flights is even more telling, five times that of any other category. Aerial application also had a relatively high accident rate.

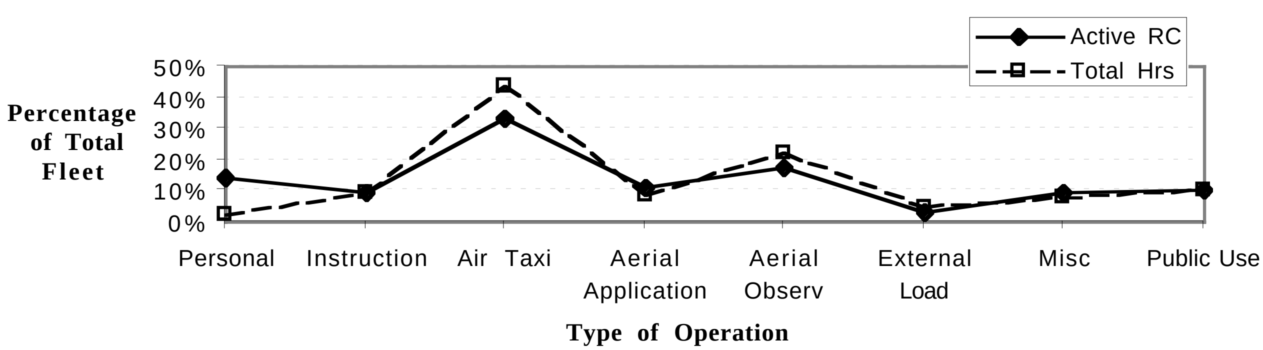

Fig. 5 Type of Operation for Total Fleet - FAA Rotorcraft Activity Survey 1989

Table 2. Accidents by Type of Operation and Cost

	Total		Low Cost		Medium Cost		High Cost		Very High Cost	
Type of Operation	#	%	#	%	#	%	#	%	#	%
Personal	221	19.0%	192	25.4%	29	9.5%				
Instruction	189	16.2%	172	22.8%	18	5.9%				
Taxi, Business	169	14.5%	54	7.1%	108	35.4%	5	6.6%	2	7.1%
Aerial Application	153	13.1%	136	18.0%	10	3.3%	7	9.2%		
Observation	110	9.4%	74	9.8%	31	10.1%	5	6.6%		
Position	80	6.9%	28	3.7%	30	10.0%	16	21.1%	6	21.4%
External Load	73	6.3%	16	2.1%	21	6.9%	29	38.4%	6	21.4%
Public	64	5.5%	33	4.4%	23	7.6%	3	3.9%	5	17.9%
Miscellaneous	106	9.1%	51	6.7%	35	11.5%	11	14.5%	9	32.1%

Table 3. Statistics for Accidents by Mission

		Personal	Instruction	Air Taxi	Aerial Application	Aerial	Observation Position	External Load	Public Use	**TOTAL**
Accidents	(#)	220	189	167	152	110	80	73	64	**1165**
	(%)	19	16	14	13	10	7	6	6	**100**
Accident Rate	Accidents/ 100k hr	44.9	9.9	2.5	9.2	2.4	N/A	7.8	3.1	**5.3**
Fatality	(%)	16	8	17	6	17	21	22	20	**15**
Conditional Probability	Fatal given accident (%)	20	9	24	6	23	21	22	27	**18**
First Event	Most frequent	Ctrl	Ctrl	Eng	Eng	Eng	Eng	Eng	Eng	**Eng**
	(%)	26	24	31	39	31	24	34	23	**27**

Note: For First Event, “Ctrl” stands for Loss of Control, and “Eng” stands for Loss of Engine Power.

Conditional probability of fatality gives another perspective. Conditional probability of fatality is the likelihood that an accident will be fatal given that an accident has happened. A mission group that has a high conditional probability has relatively more severe accidents. Public use, air taxi and aerial observation have a high conditional probability of fatality, while none of these categories has an especially high accident rate. This finding reinforces what the damage and injury analyses revealed: pilots of expensive helicopters seem to handle minor problems well, and thus the few accidents they do have are generally catastrophic.

The first event helps illuminate some of the differences in accident rate. The first event is the first problem that signals the start of an accident sequence. It differs from cause in that it may not indicate the reason the problem is occurring. One example of first event is loss of engine power. The corresponding cause might be fuel exhaustion or system failure. Accidents during personal and instructional missions stand out for beginning with loss of control. For all other groups the most common first event is engine failure. For more details on first event analysis, see NASA TM in press.

NASA Safety Initiatives

The safety initiatives attempt to address the issues identified. Helicopter accidents can be divided into two distinct groups by type of pilot, private or professional. Solutions for preventing and mitigating accidents will be quite different for private pilots than they will be for professional pilots. NASA’s program will develop solutions for the private pilot. The rotorcraft safety projects supported by NASA focus on providing training aids to flight schools and using the internet to distribute safety information. Training aids and websites were chosen as initial projects because they can be developed fairly quickly compared to cockpit devices that involve more lengthy research programs and regulation approval processes.

A NASA helicopter safety website has been created which provides free helicopter specific safety information. The helicopter industry, being so small and varied in mission, did not previously have a central safety clearinghouse. Helpful information, previously difficult to access, is now assembled in one location. Computerized training modules have also been recommended. These modules would be used in conjunction with ground instruction and

Table 4. NASA Civil Helicopter Safety Website Structure

Mission	This section presents accident statistics, discusses risk factors, and offers advice specific to each mission, and links (or will link) to the appropriate risk factor page. Missions included are aerial application, aerial observation, air medical services, business, external load, instruction, personal, and public use.	
Risk Factors	This section will highlight the hazards associated with each risk factor, offer advice and link to potential solutions in the safety aid section. Risk factors addressed will include aircraft system failures, training, poor crew coordination, inadequate decision-making/ poor judgement, engine failure, autorotations, improper use of flight controls, loss of rpm or airspeed, inadequate preflight, weather (ceiling and visibility), wires and other obstacles, flying an unfamiliar aircraft, and maintenance.	
Columns	**Subject**	**Updated**
	FAA Update on changes in regulations	Quarterly
	Bell Helicopter/TEXTRON's Heliprops-Human AD safety publication	Quarterly
	Aviation Safety Reporting System – Callback, Directline - analyses of incident database	As received
	Accident summaries and statistics	Monthly
	Ray Prouty's articles from Rotor & Wing	Monthly until done
	Safety Brief – analysis of particular scenario by NASA researcher	As received
	Professional Aviation Maintenance Association – articles by PAMA president	As received
	Autorotate magazine – pertinent safety-related excerpts	As received
Safety Aids	This section provides information on products available which might help a pilot to fly more safely or increase awareness. Products are split into categories including videos, books, publications, brochures, checklists, wire alerting/protection devices, other safety products, and training aids. NASA safety research information will be added soon.	
Links	The links page will bring up the web pages of other groups which have helicopter safety information, including the Federal Aviation Administration, National Transportation Safety Board, Transport Canada, Aviation Safety Reporting System, Helicopter Association International, American Helicopter Society, Flight Safety Foundation, Airborne Law Enforcement Association, National Emergency Medical Service Pilot Association, helicopter manufacturers, and others.	

flight school. The goal of these efforts is to provide students with a better understanding of how helicopters work and with improved decision-making skills. Once exposed to these learning aids, we expect students to be better prepared to handle emergencies and avoid accidents. These two projects are aimed at raising safety awareness and increasing pilots' understanding of helicopter operations.

Safety Website

The NASA Civil Helicopter Safety website is intended to raise private pilots' awareness of safety issues. The website brings together safety information that is easily accessible. The website structure is explained in Table 4.

Currently, the website is receiving about 20,000 hits per month. Plans include adding a safety article index, risk factor section, and completing the mission section. The website will continue to be updated with material to keep the website fresh and interesting so that the helicopter community will continue to check in.

Training Modules

Training aids aimed at students and instructors could reduce the high number of instructional accidents. It is anticipated that a student who fully understands how the helicopter operates would have better judgement in handling unusual attitudes and difficult situations than a student who lacks the same comprehension. While this project directly targets instructional accidents, improved training may also prevent other types of accidents long after the training program has ended. These training modules may help new pilots to avoid lack of situational awareness, violation of aircraft performance limits, and other problems, that lead to accidents.

Computerized training modules would augment ground school and coordinate with in-flight lessons. They should improve the effectiveness of ground school and use instructors' time more efficiently, thereby providing a low cost safety measure. These training modules may employ an interactive three-dimensional animated model to illustrate the physics of helicopter operation, including many undesirable flight conditions. Visualizing the forces and interactively experimenting should help students to better understand how to operate a helicopter.

The topic deemed most critical by flight schools for training was Hazardous Maneuvers. Since hazardous maneuvers can not safely be performed or practiced in flight, student need to understand how to avoid situations leading to these maneuvers and how to handle them if they do occur. Particular emphasis would be on recognition of a failure or condition and teaching the initial reaction to mitigate the problem.

Basic aerodynamics, and aircraft performance will comprise two more modules. Exceedance of flight performance parameters is a significant factor in causing accidents. Students need to understand how a helicopter operates as well as its capabilities and limitations.

Drawings, models and instructors explanations are often not enough to help a student understand the unseen forces acting on a helicopter. Explicit visualization in an interactive setting is more effective. This module might also highlight common mistakes and misconceptions.

A human factors oriented module would focus on situational awareness. This includes awareness of pilot states, aircraft states, communication, problem clues, obstacles, and weather.

The final module deals with instructor training. Quite often students go straight from the student role to the instructor role to get more flight hours in their logbook. While flight schools do provide some additional training for flight instructors, there is no standardized training. This module would help the instructor learn how to teach material, deal with a variety of students, and judge when to intervene to prevent accidents. It would present the top ten mistakes of teaching both in the classroom and in flight.

One training module under development is the Course of Action Training Tool (COATT). COATT is intended to help pilots learn decision-making skills to prevent pilot-induced hazardous situations from developing.[6]

CONCLUSIONS

For the time period examined, helicopters have a relatively high accident rate. They experience an accident rate ten times that of airliners. Yet helicopters, general aviation, and airliners are comparable in terms of the likelihood that an accident will be fatal. Helicopter accidents are, in general, more frequent that airliner accidents, but not worse in severity.

The high rate of helicopter accidents does not appear to be a product of the uncontrolled helicopter flight environment. Neither does it appear to be the product of unique helicopter missions. While there are specific hazards associated with certain helicopter missions, these factors do not significantly contribute to the high accident rate. The primary factor driving the high rate appears to be the skill level of the private pilot.

In fact the more expensive helicopters, which perform most of the specialized missions, show a low accident rate, comparable to that of airliners. The high accident rate derives from the lower cost end of the fleet. Lower cost helicopters have more accidents than do higher cost helicopters, despite flying fewer total hours. While lower cost helicopters have more accidents overall, they have generally less-serious accidents. The high-end fleet's similarity to airliners is due to the similarity of their professional pilots to airline pilots.

While breaking down accident statistics by cost shows that lower cost helicopters have the higher accident rate, the underlying cause is more likely the type of pilot. Indeed the most apparent dichotomy in the accident data is the division between accidents involving personal pilots and those involving professional pilots. Personal pilots tend to fly low cost aircraft in benign environments. They have accidents that are often a direct result of their own errors. Even when pilot error is not the primary cause, it is often a major factor leading to or exacerbating the accident. Professional pilots are highly trained and have ample flight experience. They fly larger, more expensive aircraft carrying passengers or valuable cargo. They may fly in hazardous environments and perform difficult tasks, such as external load operations, and maneuvers near objects. Yet, their accidents are usually a result of equipment factors rather than pilot error.

NASA's program focuses on developing solutions for the private pilot in the form of a safety website and computerized training modules. NASA's civil helicopter safety website is accessible to all pilots, but is intended to help the unregulated personal pilots. The website disseminates pertinent safety information, including causes, risk factors, safety advice, links, and available safety aids. We intend to develop computerized training modules to address the risks inherent in flight training. These modules should help new pilots gain increased understanding of a helicopter's operation. These modules may also help students to avoid lack of situational awareness, violation of aircraft performance limits, and other problems, that lead to accidents.

APPENDIX A

NTSB Definitions of Damage [7]

The following definitions of terms used in this report have been extracted from NTSB Part 830 of the Federal Aviation Regulations. These regulations are included in most commercially available FAR/AIM digests and should be referenced for detailed information.

Aircraft Accident -- An occurrence incident to flight in which "as a result of the operation of an aircraft, any person (occupant or non-occupant) receives fatal or serious injury or any aircraft receives substantial damage."

Destroyed means that an aircraft was demolished beyond economical repair; that is, substantially damaged to the extent that it would be impractical to rebuild it and return it to an airworthy condition.

(This may not coincide with the definition of "total loss" for insurance purposes. Because of the variability of insurance limits carried and such additional factors as time on engines and propellers and aircraft condition before the accident, an aircraft may be "totaled" even though it is not considered "destroyed" for accident investigation purposes.)

Substantial Damage:

1. Except as provided below, substantial damage means damage or structural failure that adversely affects the structural strength, performance, or flight characteristics of the aircraft, and that would normally require major repair or replacement of the affected part.

2. Engine failure, damage limited to an engine, bent fairings or cowling, dented skin, small puncture holes in the skin or fabric, ground damage to rotor or propeller blades, damage to landing gear, wheels, tires, flaps, engine accessories, brakes, or wing tips are not considered "substantial damage."

(As with "destroyed" above, the definition of "substantial" for accident investigation purposes does not necessarily correlate with "substantial" in terms of financial loss. Contrary to popular misconception, there is no dollar value that defines substantial damage. Because of the high cost of many repairs, large sums may be spent to repair damage resulting from incidents that do not meet the NTSB Part 830 definition of "substantial damage.")

Minor damage is damage that does not qualify as substantial, such as that under "substantial damage" above.

APPENDIX B

NTSB Definitions of Type of Operation

The purpose for which the aircraft is being operated at the time of the accident:

On-Demand Air Taxi -- Revenue flights conducted by commercial air carriers operating under 14 CFR 135 that are not operated in regular scheduled service, such as charter flights, and all non-revenue flights incident to such flights.

Personal -- Flying by individuals in their own or rented aircraft for pleasure or personal transportation, not in furtherance of their occupation or company business. This category includes practice flying (for the purpose of increasing or maintaining proficiency) not performed under supervision of an accredited instructor and not part of an approved flight training program.

Business -- The use of aircraft by pilots (not receiving direct salary or compensation for piloting) in connection with their occupation or in the furtherance of a private business.

Instruction -- Flying accomplished in supervised training under the direction of an accredited instructor.

Executive/Corporate -- The use of aircraft owned or leased and operated by a corporate or business firm for the transportation of personnel or cargo in furtherance of the corporation's or firm's business, and that are flown by professional pilots receiving a direct salary or compensation for piloting.

Aerial Application -- The operation of aircraft for the purpose of dispensing any substance for plant nourishment, soil treatment, propagation of plant life, pest control, or fire control, including flying to and from the application site.

Aerial Observation -- The operation of an aircraft for the purpose of pipeline/powerline patrol, land and animal surveys, etc. This does not include traffic observation (electronic news gathering) or sightseeing.

Other Work Use -- The operation of an aircraft for the purpose of aerial photography, banner/glider towing, parachuting, demonstration or test flying, racing, aerobatics, etc.

Public Use -- Any operation of an aircraft by any federal, state, or local entity.

Ferry -- A non-revenue flight for the purpose of (1) returning an aircraft to base, (2) delivering an aircraft from one location to another, or (3) moving an aircraft to and from a maintenance base. Ferry flights, under certain terms, may be conducted under terms of a special flight permit.

Positioning -- Positioning of the aircraft without the purpose of revenue.

Other -- Any flight that does not meet the criteria of any of the above.

Unknown -- A flight whose purpose is not known.

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